Green Building Performance Evaluation: Measured Results from LEED-New Construction Buildings

Cathy Turner and Mark Frankel, New Buildings Institute

ABSTRACT

Is LEED delivering actual energy savings? This study addresses that question with a post-occupancy assessment of 121 LEED buildings across the country. Input to the study consisted of energy bills and brief descriptions of actual building use from owners, plus modeled energy usage information from the USGBC's LEED submittal files. The actual building performance was viewed through several whole-building metrics: energy use intensity (EUI) relative to national averages, Energy Star ratings, and energy use levels relative to the initial ASHRAE 90.1 modeling. Two overall results emerged. First, across each of these varied measurements, LEED building performance averaged 25 – 30% better than the benchmark. However, there is also wide variation within the individual results, even for similar building activities and climate zones, suggesting potential for significant further improvements. This paper presents general EUI patterns, Energy Star ratings, and their relationship to LEED energy credits. (Further discussion of the effectiveness of the initial modeling as a tool to predict energy savings is presented as a separate paper.) The discussion also covers the study process and current challenges to such efforts. As an incentive to participate in this aggregate study, owners were given a report of their individual building results including, where desired, an optional occupant survey to further round out the view of building performance.

Introduction

Studies to-date of measured green building performance have been limited by a number of factors, including cost of gathering data, difficulty in identifying appropriate benchmarks, and the relatively few buildings constructed to similar standards. The growth of the LEED certification system and the development of the Energy Star tool for rating commercial building energy performance now make it possible to begin more comprehensive studies. In January 2007, the USGBC invited all 552 certified LEED for New Construction buildings to participate in a study of measured whole-building energy usage. The primary objective of this exploratory study was to begin to quantify the energy performance of LEED buildings, identifying savings associated with the LEED program and relationships among various performance metrics. Secondary objectives included providing performance feedback to individual building owners and identifying possible ways to standardize such reviews for all LEED buildings in the future.

This paper includes a) Study Procedures; b) Participant Characteristics; c) Results of energy intensity and Energy Star metrics, and d) Discussion and recommendations. A separate paper analyzes the relationship of measured results to initial modeling. (Frankel, 2008)

Procedures

Invitations were sent to all 552 LEED for New Construction version 2 (NCv.2) buildings. NCv.2 comprises about ¾ of total certifications within the various LEED programs and provides the largest coherent subset on which to base energy analysis.[1] The only additional requirement for participating was the ability to provide at least one full year of measured post-occupancy energy usage data for the entire LEED project. As an incentive to participation, owners were given an individual report of their own building performance. That report included, when desired, the results of an occupant survey of the building's functional comfort.

The final study includes the 121 projects that provided measured energy information, 22% of the total number certified. Another 128 owners gave some response but did not meet the full requirements. Some had not occupied the building for a full year. A few submitted data that was ultimately excluded as incomplete. The primary barrier, however, was inability to provide measured usage data for the LEED facility. These were typically cases where 1) the building was part of a campus metered only as a whole, 2) the project covered just an addition not metered separately from the previous space or 3) energy bills included significant outdoor energy (ball field lighting, etc.) that could not be accurately isolated and materially distorted results. Clearly one prerequisite for achieving useful performance feedback is the basic metering of each project.

Measured energy usage and basic building information was usually obtained directly from owners or managers, at the whole building, monthly energy bill level. "Measured energy" used here refers to purchased site energy, excluding onsite renewables, for the most recent twelve months provided by the owner. To create the largest possible data set while avoiding requests from multiple sources to the same owner, we also include some data from concurrent studies and published reports.[2] Of the 121 buildings, 75% provided new data directly.

Benchmark Sources

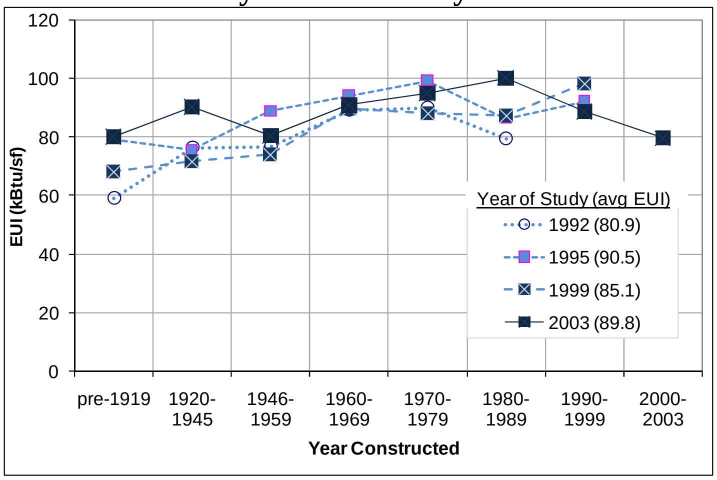
National building stock averages came from the 2003 Commercial Building Energy Consumption Survey (CBECS) energy use intensities (EUIs). This quadrennial survey by the Energy Information Agency gathers data on consumption and other characteristics from thousands of buildings, representative of the entire national building stock. The relatively new LEED buildings were compared to all vintages of CBECS buildings for two main reasons: CBECS demonstrates no strong pattern of lower use in newer construction, and there is a relatively low observation count for 2000 and later buildings in the 2003 CBECS.

Figure 1 displays the average EUIs from the last four CBECS studies, with results of each subdivided by construction period. The *vertical* pattern of points shows the change in EUI from survey to survey for one construction vintage cohort. These survey-to-survey changes reflect a combination of change in performance over time for the vintage and change in survey procedures and definitions. Each *horizontal* line is based on a single survey, showing the pattern of EUIs by construction vintage within that survey. For all historical vintages through the 1990s, the average newer building EUI does not appear notably lower than the overall average. The 2000-2003 vintage sample from the most recent survey should be most reflective of stronger recent building codes, and it does suggest a promising trend. However, that most recent point was based on just 410 observations, across all building types, regions, sizes etc. To further explore

[1] These LEED NCv.2 buildings are referred to simply as LEED buildings throughout the rest of the report.
[2] Prior published studies were Diamond et al, 2006, which included LBNL analysis of federal building data collected by DOE/FEMP, and Turner, 2006. Other data sources included Energy Star for currently labeled buildings, the Oregon SEED program, and a concurrent, independently conducted data collection.

the impact of vintage in the benchmark choice for this study, the Results section does compare EUIs by building type to both the all-vintages CBECS and the 1990–2003 vintages only.

Figure 1. CBECS EUIs by Year of Survey and Year of Construction



Energy Star ratings for eligible participating building types were obtained using the EPA's Portfolio Manager. These ratings rank a building's energy usage relative to similar buildings across the country, normalized for weather, activity and other key operational characteristics.[3] For example, the office building Energy Star Ratings consider average weekly operating hours, the number of occupants and the number of computers. Site energy, by fuel, is converted to source energy in these calculations. Sixty of the participating buildings had activity types eligible for an Energy Star rating.

Accuracy and Precision

Submitted information was reviewed for reasonability, but not audited or otherwise verified. Procedural checks included questioning data not consistent with general information on fuels, end uses, building activities and tenants. Owners received individual building reports for comment or correction, accompanied by specific questions when key information appeared missing or inconsistent.

Even with 121 participating buildings, data volume can be insufficient for statistically credible differences when subdivided among multiple variables, particularly with high variability in individual performance results. Thus, the study is a beginning, not the final definitive analysis. Many patterns presented in the results should be considered approximate and suggestive of areas for further exploration, not precise performance levels. Similar categories are sometimes grouped to avoid extremely low counts in any one subgroup. For example, results by LEED certification level show gold and platinum levels combined because the study includes only two platinum buildings. Results by number of Energy Optimization points are grouped into four point ranges because there is not enough data for division among the individual 0 through 10 point levels. Medians, denoting the level at which half the observations are higher and half

[3] The Energy Star rating system was updated October 1, 2007, to reflect the most recent CBECS survey results and refined calculation methodologies. All ratings reported in this study were calculated *before* this revision. Anticipated changes to individual ratings from the new methodology were small. The difference would not be expected to affect any overall conclusions of this study, although results for individual buildings may vary slightly.

lower, are used throughout this report to reflect the average results of the LEED buildings, providing a consistent basis for more robust averages in subgroups with few observations.

None of the performance metrics used in this study provides a perfect basis for precisely quantifying savings. However, viewing results from multiple perspectives offers a good general sense of accomplishments thus far, particularly when the general conclusions from multiple metrics agree. This exploratory view provides the basis for designing the structure of more complete future analyses.

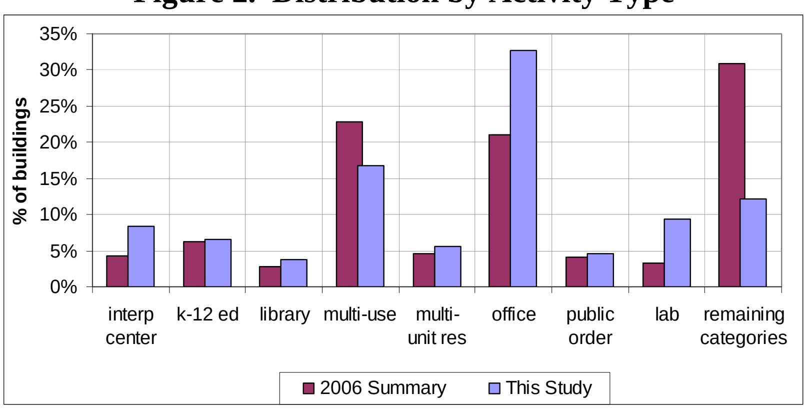
Participant Characteristics

Characteristics of participating buildings were similar to those of all LEED buildings. This alignment shows that major building segments were not omitted in the results, even though the study participants were volunteers rather than a statistically random sample. In the comparisons below, "2006 Summary" refers to all LEED certifications through July 2006, from a prior review (NBI, unpublished) that examined many relationships and patterns for energy credit achievement and initial modeling projections. "This study" refers to the 121 buildings that submitted measured post-occupancy energy data in 2007.

Building Activity Type

Office buildings are the dominant category in this study and in the LEED building stock as a whole. This study's apparent higher proportion of office buildings, and lower concentration of multi-use and miscellaneous remaining types, comes largely from better categorization with more complete information on the participating buildings. Also, multi-use buildings were categorized by principle activity type when that constituted 80% or more of total floor space.

Figure 2. Distribution by Activity Type

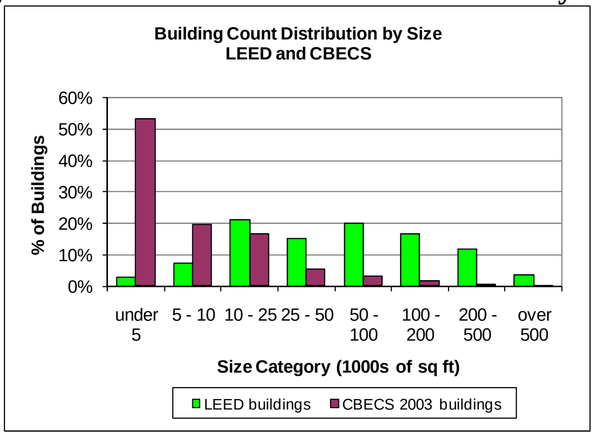


Types with 3 or fewer participating buildings in this study are grouped under "remaining categories."

By Size

The size distribution for study participants is similar to that of all LEED buildings, with an average size just over 110,000 square feet and about half the buildings in the range of 25,000 to 200,000 square feet. That result is in marked contrast to the size distribution for all national building stock as reported by CBECS, with 73% of all buildings below 10,000 square feet and an average size of 14,700. (Figure 3)

Figure 3. LEED and CBECS Distribution by Size



The significant difference in size distribution between LEED and CBECS building stock is one example of why average LEED and CBECS performance may not be directly comparable. The size impact is further discussed in the Results section for EUI comparisons.

By Climate Zone

70% of participating buildings were in cool zone 5 (ASHRAE), including cities such as Denver and Boston, or mixed zone 4, with cities such as Seattle and St. Louis, a similar result to that for all LEED buildings. Because of the low LEED building counts in the hot and cold zones, the energy analysis by climate zone in the following Results section groups together the warm–hot zones and the cold–very cold zones.

Results

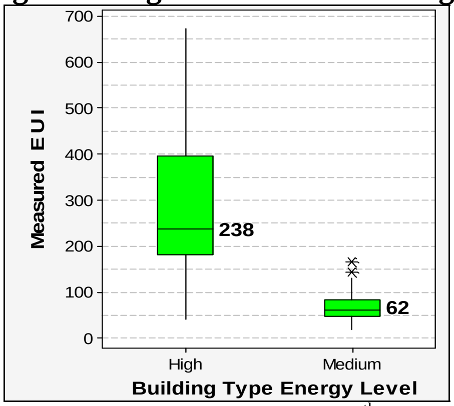
This section presents results for measured whole building EUIs in relation to national CBECS averages and for Energy Star ratings of participating buildings.

Energy Use Intensities

The median EUI for all LEED buildings is 69 kBtu/sf, 24% below the national building stock average from the 2003 Commercial Building Energy Consumption Survey (CBECS) for all building types. [4] Participants were divided by primary activity into two categories: those with high energy activities driven largely by plug or process loads such as labs and data centers, and those with medium energy activities with plug loads more characteristic of an office building. The overall LEED median of 69 kBtu/sf includes 21 High Energy Type buildings, which have a median EUI of 238 kBtu/sf, while the Medium Energy Type median is only 62. (Figure 4)

[4] As described in the section on Accuracy and Precision, medians are used throughout this report for LEED building averages. The published CBECS averages cited here use means, and this difference reduces the precision of the comparison between the two data sources.

Figure 4. EUI Ranges for High and Medium Energy Type Categories

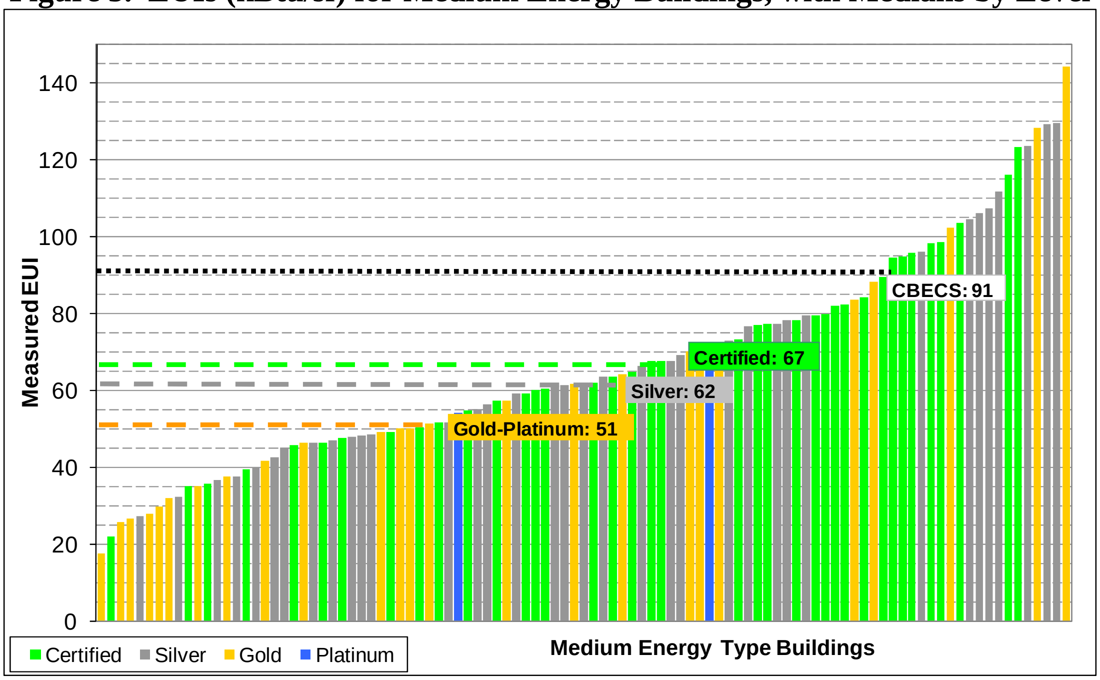


Boxes show the range of values between the 75th and 25th percentiles.
Labeled center line shows median value. All EUIs in kBtu/sf

The measured performance results in the following sections are based on the Medium Energy Types unless noted otherwise. The wide variability of the High Energy Type EUIs, and the confounding effects of interactions between process requirements and basic building systems loads, would require a more complex and detailed analysis of these project types.

Figure 5 shows measured EUIs for all the study's Medium Energy Type buildings, plus the overall CBECS national average and LEED medium energy medians by certification level. These median EUIs, when expressed as a percentage of the overall CBECS average, are 26% lower (better) for certified projects, 32% lower for silver and 44% lower for gold-platinum.[5]

Figure 5. EUIs (kBtu/sf) for Medium Energy Buildings, with Medians by Level



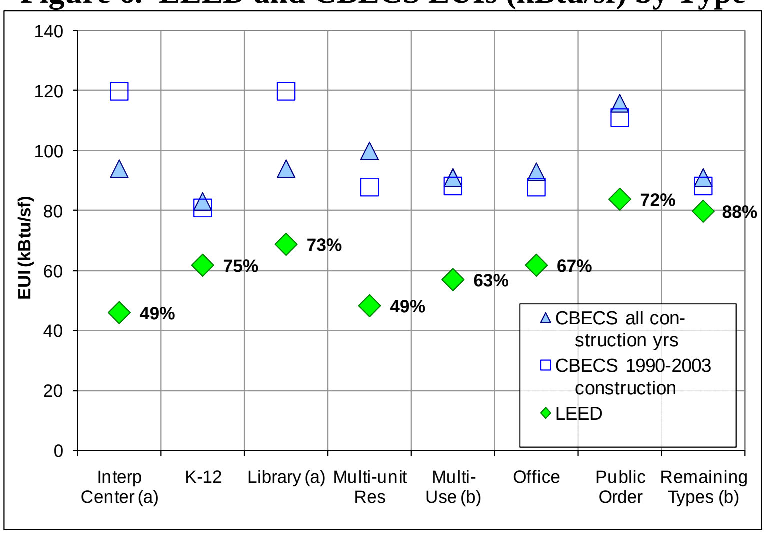
[5] Because the study included only two platinum buildings, gold and platinum results are combined in comparisons by certification level

The above averages combine many activity types for buildings in the LEED study, and the overall CBECS average includes all types of commercial building stock, from high energy labs to vacant warehouses. The next section looks at ratios by activity type.

By Type

LEED median EUIs average well below CBECS for each main activity type in the study. The grouping and definition of activity types is not identical between CBECS summaries and the LEED data, making some categories less directly comparable than others and preventing a simple comparison of overall type distribution between the study and CBECS. Offices are the single most common type for the LEED data and do have a direct match in CBECS. For these projects, the LEED median is 67% of the CBECS average. Figure 6 shows two sets of CBECS averages: all vintages and only construction in 1990 and later. (As described under Benchmark Sources, the 2000-2003 vintage alone has too few observations to permit reasonable benchmark division by type.) For most types, the two CBECS numbers are similar. For the libraries and interpretive centers (part of the CBECS "public assembly" type), for which the newer CBECS buildings have a much higher average EUI, further investigation would be required to identify other characteristic differences that may be driving the change.

Figure 6. LEED and CBECS EUIs (kBtu/sf) by Type



(a) CBECS average for Public Assembly used for the Interpretive Centers and Libraries
(b) CBECS average for all building types combined used for Multi-Use and Remaining Types categories.
LEED percentages show the ratio of LEED to CBECS for all construction years

As noted earlier, CBECS building sizes are more heavily weighted toward the small end than are the LEED buildings. Table 1 focuses only on offices, the most common activity type in the study and shows LEED EUIs to be lower than CBECS for each size group. When both LEED and CBECS EUIs are averaged across size groups using the LEED size distribution, the LEED median is 34% below CBECS and the LEED mean is 28% below CBECS. The relatively wide size ranges in Table 1 were needed to achieve at least 5 LEED observations in each group.

Table 1. LEED and CBECS Office EUIs by Size Range

Size range (Sq Ft)	CBECS EUI (kBtu/sf)	LEED Median EUI (kBtu/sf)	LEED Median LEED/CBECS	LEED Mean EUI (kBtu/sf)	LEED Mean LEED/CBECS	LEED N
under 25,000	80	46	58%	46	58%	10
25,001- 100,000	91	66	73%	72	79%	7
100,001 - 200,000	101	77	76%	78	77%	10
over 200,000	105	80	76%	79	75%	8
Total (with CBECS EUIs weighted according to LEED size distribution	94	62	66%	68	72%	35

The above table also shows both the mean and the median for the LEED data. As noted earlier, the median is used as the average throughout this report for LEED averages, to minimize the impact of extreme values in groupings with small counts. The mean is used in published CBECS averages.

Some project types above have few data points in this study. Table 2 gives more detail on counts, measured EUI levels and ranges by building activity type.

Table 2. LEED and CBECS EUIs (kBtu/sf) by Type

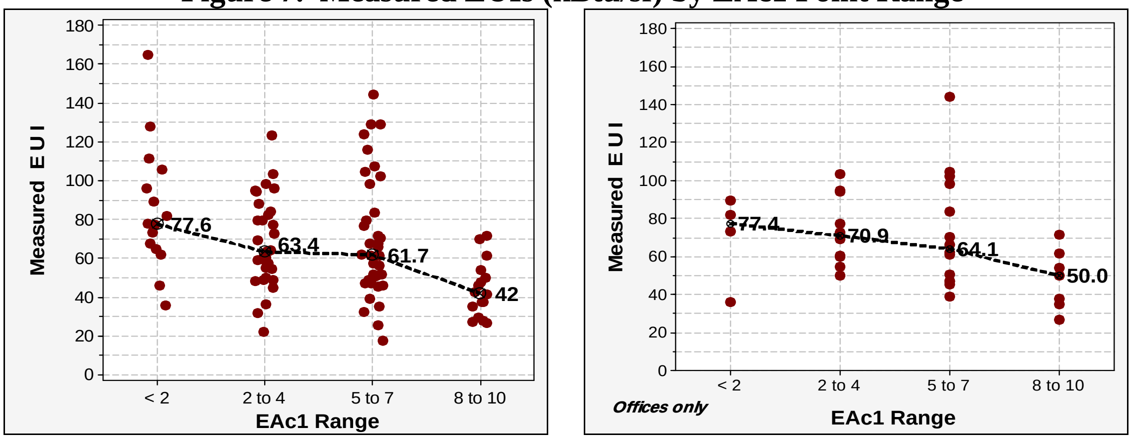
	LEED N	Measured EUI (P25/**P50**/P75) (a)	CBECS (b)	LEED / CBECS
Interpretive Center	9	33 / **46** / 87	94	49%
K-12 Ed	7	46 / **62** / 77	83	75%
Library	4	40 / **68** / 86	94	73%
Multi-Unit Res	6	42 / **49** / 52	100	49%
Multi Use (b)	18	35 / **57** / 66	91	63%
Office	35	50 / **62** / 84	93	67%
Public Order	5	79 / **84** / 120	116	72%
Remaining Types (b)	16	64 / **80** / 121	91	88%
All Medium Energy Types	100	47 / **62** / 82	**91**	**68%**
Data Center	6	138 / **216** / 519	164	132%
Health Care	1	* / **238** / *	188	127%
Lab (a)	10	200 / **284** / 465	356	80%
Recreation	2	* / **126** / *	164	77%
Supermarket	2	* / **225** / *	200	112%
All High Energy Types	21	181 / **238** / 395	(c)	
ALL	**121**	**69**	**91**	**76%**

(a) P25 = 25th percentile; P50 = median; P75 = 75th percentile. * indicates too few data points for quartile determination.
(b) CBECS average for all types used for Multi-Use and Remaining Types categories. Labs21 average used in place of CBECS for Labs.
(c) CBECS principal activity categories are insufficient to separate EUIs just for these high energy types.

By Energy Optimization Credit Level

The left chart in Figure 7 shows median EUIs improving somewhat as LEED energy optimization points (EAc1) increase, and a narrowing of variability at the 8 to 10 point range.[6] The right-hand chart, restricted to office buildings to eliminate type variability, continues to show a wide range of results at the middle point levels and improvement at the high end.

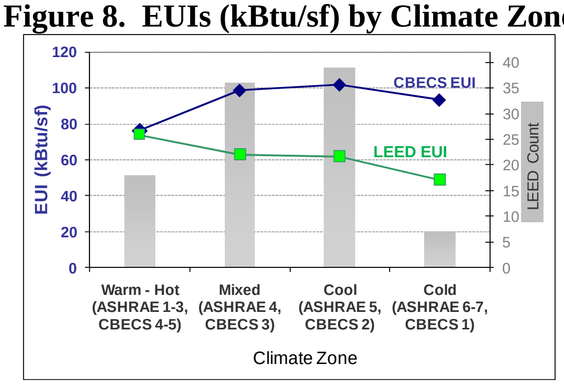
Figure 7. Measured EUIs (kBtu/sf) by EAc1 Point Range



By Climate Zone

For all but the warm-to-hot zones, LEED building EUIs average 35 to 50% better than CBECS. For the warmer zones, the median LEED result is virtually the same as CBECS. (Figure 8) The warmer zone performance is based on relatively few buildings, but the result raises questions about whether these climates pose additional challenges for achieving energy efficiency. A difference in size distribution for the warmer zone buildings could potentially contribute to the observed result, but the data is not sufficient to either support or refute that hypothesis. Additional study in this area is suggested.

Figure 8. EUIs (kBtu/sf) by Climate Zone



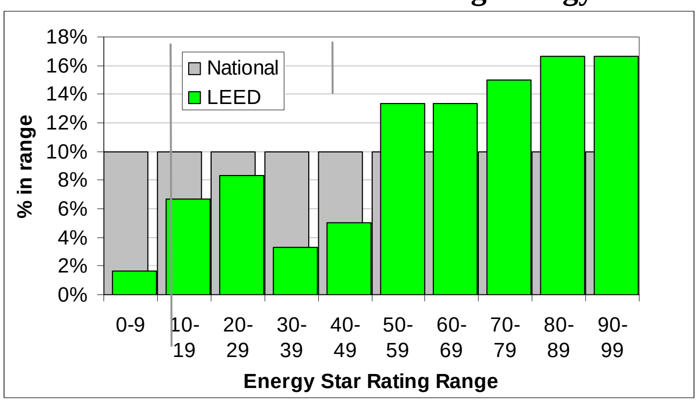
6 As noted earlier, the variability within categories for most results presented in this paper is too great for differences between categories to be statistically significant. The results for projects with 8 to 10 EAc1 points constitute one exception to that rule. For all medium energy buildings combined, the EUIs of those buildings achieving the highest energy optimization points are less than the EUIs of buildings with fewer points at the 95% confidence level.

Energy Star Ratings

For the 60 buildings in the study with activity types eligible for Energy Star ratings, those normalized results should give a more precise assessment of relative performance than a simple comparison to broad CBECS averages. Furthermore, because each building's rating is normalized to its activity type, it is possible to combine all rated building types in Energy Star summaries. Thus, the ratings presented in this section are for all 60 participating buildings covered by the rating system, including high energy type supermarkets.

The median LEED Energy Star rating was 68, compared to an assumed national building stock median of 50. These ratings represent performance percentiles, so a rating of 50 means 50% of similar buildings perform worse (use more source energy per square foot) than the rated building. Figure 9 shows that 3/4 of LEED buildings have ratings above the national building stock median of 50. Nearly half (47%) had Energy Star ratings of at least 75, and 17% had ratings above 90. At the other extreme, 15% of the LEED buildings in this study have ratings below 30.

Figure 9. Distribution of LEED Building Energy Star Ratings

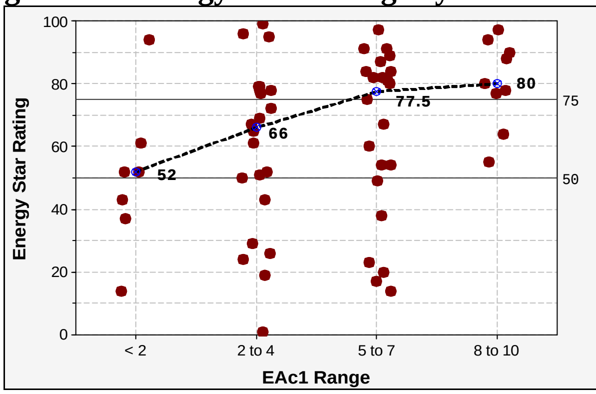


The wide range of ratings shown in the above graph does not seem to be a function of building type. The office building type alone, which comprises over half the buildings eligible for Energy Star ratings, displays nearly as much spread in ratings as the entire group.

By Energy Optimization Credit Level

Median Energy Star ratings increase for buildings with higher levels of EAc1 points, seen in Figure 10. Again, there is a great deal of variability in individual results. Further investigation of drivers of performance variability was beyond the scope of this study but could support improvement of future program performance.

Figure 10. Energy Star Ratings by EAc1 Range



Occupant Survey Results

To provide a more complete view of building performance, a web-based occupant survey was offered to participating owners. Results of these surveys demonstrate whether a high performance building is both energy efficient *and* a functionally comfortable work environment. This systematic approach is more complete than relying on anecdotal comments or complaints. The brief online survey used, modeled after *Buildings In Use* work done by Jacqueline Vischer (Vischer and Preiser, 2005), asked occupants to rate the key functional comfort areas of acoustics, lighting, temperature and air quality, as well as the overall building. Table 3 summarizes the average comfort rating for the LEED buildings participating in these surveys for each comfort dimension. A rating of zero is a neutral response, neither comfortable nor uncomfortable. The typical building averages for comparison are the average normative scores from the 1000-plus cases reviewed under the *Buildings in Use* (BIU) program.

Table 3. Occupant Comfort Ratings

(-2 = most uncomfortable, +2 = most comfortable)

	Acoustics	**Lighting**	**Temperature**	**Air quality**	**Helps getting work done**	**Overall satisfaction**
LEED Median	0.14	1.14	0.56	1.05	0.42	1.06
BIU Average	0.00	0.60	0.10	-0.20	*	*

* BIU averages available only for individual comfort dimensions, not the overall summary metrics

For each dimension, the LEED building ratings were positive and exceeded BIU normative scores. These comparisons do help show that the LEED buildings that were surveyed are working well, not just saving energy at the expense of occupant comfort. The data here are insufficient, however, to demonstrate whether LEED buildings achieve higher comfort than new non-LEED construction, in the absence of a comparable benchmark set of new non-LEED buildings, The lowest-rated dimension was acoustics, averaging near neutral for both LEED projects and all buildings. Such results are often seen as related to open office floor plans, which are common in green and non-green buildings alike.

Discussion

On average, LEED building EUIs are 25–30% better than CBECS and average savings increase as performance goals increase with higher LEED certification levels. Gold and platinum buildings' average EUIs are 45% better than non-LEED buildings. Approximately half the LEED projects have Energy Star ratings that place them in the top quartile of comparable buildings.

Within each of the metrics, measured performance displays a large degree of scatter, suggesting opportunities for improved programs and procedures. Measured EUIs for medium energy type buildings vary by a factor of 5 from lowest to highest. This variability is still less than for overall national building stock and not inconsistent with earlier studies of green building performance. For example, CBECS EUIs for office buildings differ by a factor of 10, *after* excluding the highest and lowest 5% of all observations. A 1994 study by LBNL saw EUIs differing by a factor of over 4, for 28 new commercial buildings participating in Bonneville Power's Energy Edge program, and a 2003 New Buildings Institute study of 157 California commercial buildings show as-constructed savings (compared to code) ranging from -100% to +50%. It is time to narrow this variability for green building programs. A follow-up study of some of the good and poor performers is underway, with an objective of identify ways to eliminate the worst results and the lessons to be learned from the best.

The experience of performing the study also suggests needed extensions to this initial analysis. Data collection must be simpler and more reliable in order to increase the amount of useful feedback for individual reporting, program evaluation, and general benchmarking purposes. The participation of only 25% of certified buildings in this study was largely the result of the difficulty of acquiring simple usage data, requiring several hours per building on the part of both the owners and the analysts just for data collection and screening. Larger green building sample sizes are needed to refine results by climate, size, and activity. Secondly, better benchmarks are needed to determine relative performance levels. Not all activity types are currently addressed by Energy Star, and CBECS survey results are available only several years after the measurement date and with limited coverage of recent buildings. Finally, improvements in LEED program quality control and follow-up are suggested, to increase the reliability of submittal information and help encourage and maintain savings.

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